DEVELOPING AGROFORESTRY-ADAPTED CEREALS USING AN EVOLUTIONARY PLANT BREEDING APPROACH

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Introduction

In agroforestry systems, interactions between the woody and non-woody components can be positive, negative or neutral, and the productivity of a system is a net result of these interactions (Jose et al. 2004). Within northern temperate regions, the main limiting resource for plants is usually light and studies have shown that shading has reduced yields in temperate agroforestry systems. For example, in a poplar silvoarable trial at three sites in lowland England, Burgess et al. (2005) reported an average 4% reduction in crop yields compared to an arable control for the first three years, increasing to 10% less between years four and six. They showed that shading by trees reduced the amount of short-wave radiation reaching the crop was 82-88% of that in the control treatment, and suggest that this accounts for the lower yields. The impact of trees on crop yields has been identified by arable farmers as a key management challenge of silvoarable agroforestry (Smith et al. 2014). Agroforestry systems can be designed to optimise resource capture by maximising positive interactions and minimising negative ones. This can be achieved by careful selection of appropriate species, and the development of arable crops specifically adapted for agroforestry systems was identified as an innovation for further development at a stakeholder workshop (Smith et al. 2014) held as part of the FP7 project AGFORWARD (www.agforward.eu).

One approach to developing agroforestry-adapted crops is the use of evolutionary plant breeding to develop varieties that are particularly well adapted to growing in close proximity to trees. Evolutionary breeding using Composite Cross Populations (CCPs) involves the inter-crossing of appropriate parents in many different bi-parental and higher order combinations (Wolfe et al. 2008), and has been used in organic and low-input systems in order to cope with the environmental variability inherent to such systems. High genetic variability within the crop is predicted to support increased yield stability in comparison to genetically uniform monocultures, and this stability has been documented for wheat CCPs in a number of studies (Wolfe 2000; Wolfe 2001; Döring et al. 2010). In silvoarable systems, it is proposed that increasing the genetic variability within the cereal crop should help to buffer against variations in biotic and abiotic conditions present in the crop alley.

The principle is to let natural selection act on these diverse crop populations to select the plants that are best suited to the prevailing conditions i.e. develop an 'alley-edge' population and an 'alley-centre' population. In 2014, a spring wheat composite cross population (CCP) was grown in plots across a crop alley at Wakelyns Agroforestry, an organic silvoarable system in eastern England. Plots of bulk CCP were harvested separately from plots on either side of the alley and the alley centre. In 2015, this seed was used to sow 12 m^2 plots in a replicated cross-over trial to test the effect of the population adapting under natural selection to each environment. This paper reports the results of this cross-over trial.

Materials and Methods

Wakelyns Agroforestry, an organic silvoarable research site was established in 1994 on 22.5 ha in eastern England, (52.4ºN, 1.4ºE). It incorporates hazel and willow short rotation coppice, and a mixed timber and fruit tree system, with cereals, potatoes, field vegetables and fertility-building leys in rotation within the 10 to 12m-wide alleys. Soils are sandy clay to clay loams (sand 49%, silt 23%, clay 28%) with soil organic matter around 5% (Smith 2016).

Composite Cross Population trial

In 2015, an experiment was established to test material selected in contrasting environments near to and away from the agroforestry tree rows. A replicated cross-over experiment aimed to compare performance of selected material in each environment based on the hypothesis that wheat lines will perform best in the environment from which they were selected (i.e. 'alley-edge' selected lines will perform better in the 'alley-edge' plots than 'alley-centre' lines). A spring wheat composite cross population (CCP) was grown in plots across a willow system agroforestry alley in 2014. Plots of bulk CCP were harvested separately from plots on either side of the alley, adjacent to the tree rows (East of Trees (EOT), West of Trees (WOT)) and the alley centre (Centre of Alley (COA)). In spring 2015, plots measuring 1.2m by 10.2m were drilled in a replicated cross-over trial in three replicated blocks in a hazel SRC agroforestry system to test the effect of the population adapting under natural selection to each environment. Yield measurements (t/ha, hectolitre weight (g), and thousand grain weight (TGW)) were carried out in autumn 2015 when the plots were harvested.

Statistical analyses

The statistical analysis was carried out using R version 2.10.0 (R Development Core Team, 2009). To identify the effect of alley location on the wheat populations, yields, hectolitre weight and thousand grain weights were analysed with a two-way ANOVA. Alley location (EOT, COA, WOT), wheat population (EOT, COA, WOT) and the interaction between the two were included as the fixed factors, and replicate block (three replicates) as the random effect.

Results

Yields ranged between 0.90 and 3.99 t/ha (@15% moisture content); hectolitre weights between 367.83g and 383.79g (@15% m.c) and thousand grain weights between 42.90 and 50.48g (@ 15% m.c.). There was a significant effect of location on yield ($F_{2,17}$= 48.89, $p<0.001$) and hectolitre weight ($F_{2,17}$= 4.81, $p<0.05$), but not on TGW. Yields and hectolitre weights were significantly higher in the centre of the alley than at either edge (**Figure 1** and **2**). However, there were no significant differences between the different populations for any of the yield parameters, and no significant interactions between the populations and their locations. This suggests that at this stage, there is no adaptation of populations to their selected locations (i.e. EOT populations do not perform any better in the EOT locations than in the other locations).

Discussion

Crop yields at the edges of the alleys were roughly half what they were in the centre of the alley, but there were no significant interactions between populations and their locations. This suggests that, in this first year, there is no evidence of adaptation to alley location. It is perhaps unsurprising that there has been no obvious adaptation over such a short period; in a five year project investigating the level of adaptation that may occur when CCPs are grown continuously at the same specific sites for a number of years, molecular data and comprehensive field trials found no evidence of wheat populations adapting to the cropping conditions under which they were grown (Girling et al. 2014). The authors attributed this to the influence of yearly fluctuations in weather conditions that counteracted any adaptation to the site-specific factors associated with cropping management and soil conditions. It may be necessary to carry out more detailed selection of high performing individual plants by hand, which are then bulked up, to develop specific ‘alley edge’ populations for agroforestry.

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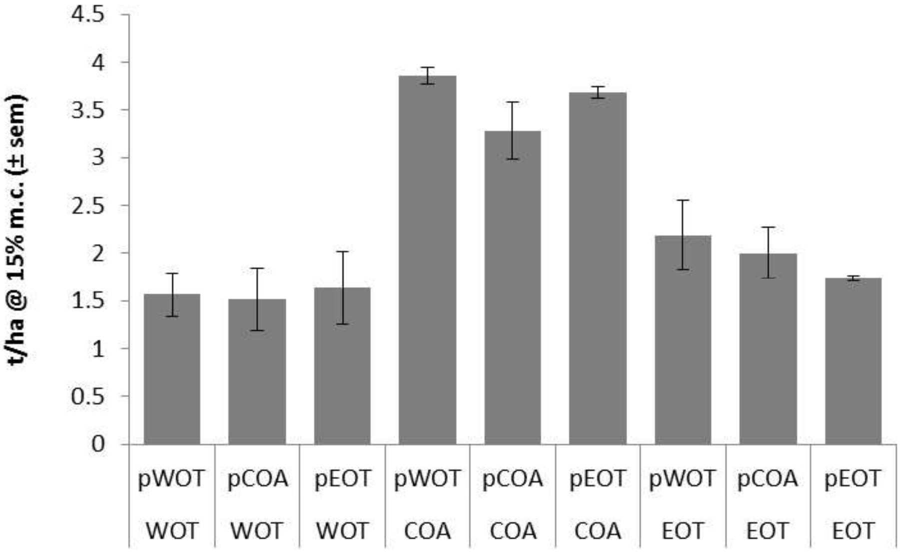

Figure 1: The mean grain yield of three composite cross populations (pWOT, pCOA and pEOT) in three positions (West of Trees WOT; Centre of Alley COA; and East of Alley EOT) across a ten meter wide alley.

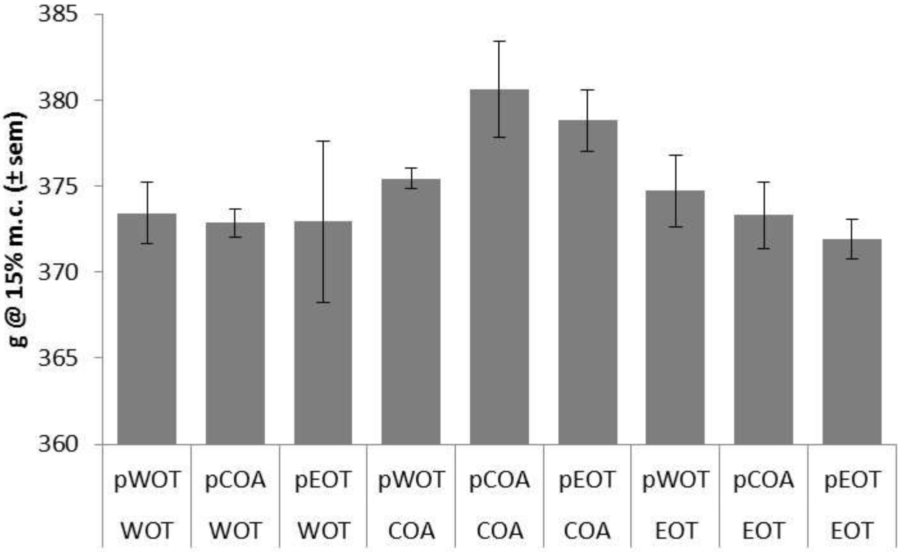

Figure 2: The mean hectolitre weights of three composite cross populations (pWOT, pCOA and pEOT) in three positions (West of Trees WOT; Centre of Alley COA; and East of Alley EOT) across a ten meter wide alley.